APPLICATION NOTE 113

Using Clamp-On Current Transformers (CTs) with Arbiter Power Analyzers

Model 931A Power Analyzer

Model 930A Three-Phase Power Analyzer

Model 929A Three-Phase Power Meter

Introduction

This application note deals with extending the current measuring range of the Arbiter Models 931A, 930A and the Model 929A power analyzers. It also covers techniques to greatly improve the accuracy, and essentially calibrate out the measurement inaccuracies associated with the use of clamp-on current transformers (CTs).

All three Arbiter power analyzers are state-of-the art instruments offering unprecedented accuracy in the measurement of parameters related to AC Power Generation, Transmission, and Distribution. Frequently, however, direct measurements are not possible since the parameter being measured is beyond the range of the instrument, or the circuit cannot be disconnected. One such electrical parameter is current. Since each of these instruments is limited to measure up to 20 Amps directly, another method is needed to extend the measurement range beyond 20 Amps.

Employing the use of a clamp-on current transformer, with a known ratio (e.g. 100:1), can effectively extend the current measuring range of these Arbiter products, and not interrupt the circuits being tested. One of the negative aspects of using a clamp-on current transformer is the measurement error due to accuracy and phase shift introduced by the clamp-on CT. Since these measurement errors can be accounted for by using the scaling feature on these power analyzers, using a clamp-on CT should no longer be a concern.

Lastly, this application note will review a very simple technique in calibrating the CT for use in the field or in the lab.

Theory of Operation

An AC clamp-on current probe (CT) is a type of current transformer. A transformer is formed essentially from two coils wound on a common iron core (Figure 1). A current I1 applied through the coil B1 induces through the common core a current I2 in coil B2. The current I2 in B2 is determined by the ratio N1 x I1 = N2 x I2, where N1 and N2 are the number of turns in each coil.

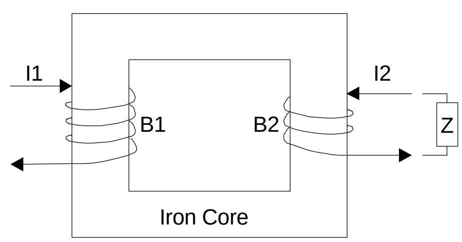


Figure 1

The same principle is applied to a current probe, which is simply an articulated magnetic core (Figure 2). The articulated core holds the coil B2, and clamps over the conductor being measured. If B1 is the conductor being measured, then N1 is the number of turns of that conductor, which is normally equal to one. When the current probe is clamped around the conductor it provides an output proportional to the number of turns of B2, such that

I2 (probe output) = (N1 / N2) x I1 where N1 = 1, or the probe output = I1 / N2. Without a CT it would be difficult to measure currents that are beyond the measuring range of the instrument. Also, by making the number of turns on the current probe equal to an even multiple (e.g. 1000:1), it is easy to provide direct readings.

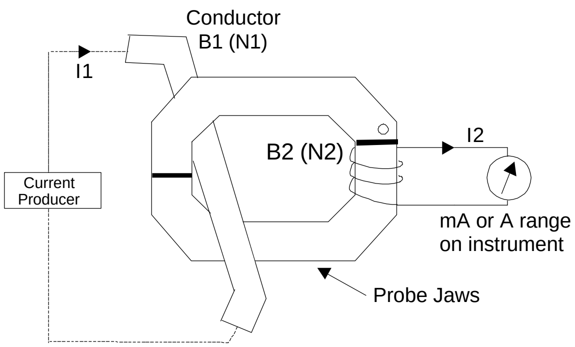


Figure 2

If N2 equals 1000, then the clamp has a ratio of 1/1000, which can be written as 1000:1. Another way to say the same thing is to say that the probe output is 1 mA/A (one milliampere per Amp).

Current probes may be used with a variety of instruments, including multimeters that require the user to make mental corrections for the scaling of the probe. For example, if the probe ratio were 1000:1 a 50 A current would read as 50 mA on a multimeter using the milliampere range. Users need to interpret the reading correctly as amps and not milliamperes. Additionally, any errors due to accuracy or phase shift introduced by the current probe need to be accounted for. If the current reading was 50 mA and the current probe has an accuracy of 1% with a phase shift of 3°, these corrections must be computed.

Scaled Readings on the Model 931A / 930A / 929A

Arbiter's Power Analyzers solve this problem by allowing the user to program these scaling values into memory. Current probe ratios may be programmed into the Model 931A/930A/929A to provide a direct readout of the current. For a probe with a ratio of 1000:1, 1000.0 could be programmed into these power analyzers to provide a direct reading of current. It would not, however account for the inaccuracy and phase shift of the probe.

In order to account for these errors, of the actual current probe being used, a simple calibration setup is required. Basic equipment could be the Arbiter Model 1040C Panel Meter Calibrator, or other current source, the test leads and current probe and the Model 931A / 930A / 929A. Setup is pictured in Figure 3.

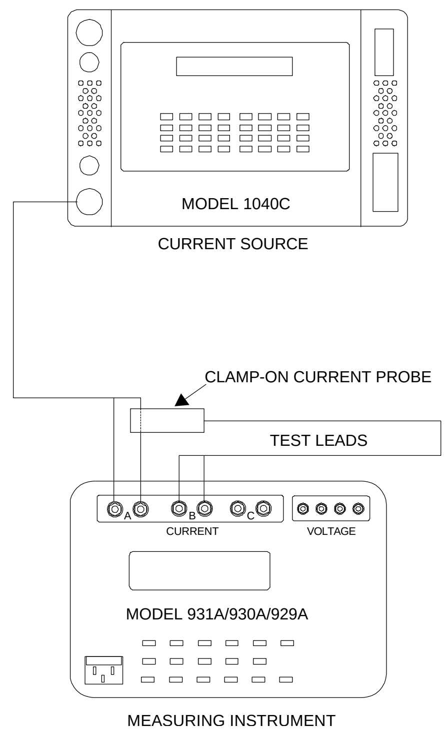


Figure 3

Figure 3 demonstrates a method of compensating for the inaccuracy and phase shift introduced by the current probe. By using a current reference (measured by a Model 931A/930A/929A) reading current directly from the source of current (the Model 1040C Panel Meter Calibrator) the current probe may be compared to the known reference.

Additionally, the same meter that reads the reference current also measures the probe current, reducing equipment and other calibration errors.

Since the Model 931A/930A/929A measures true RMS values to 0.05% (3 kHz bandwidth), any source of current may be used for reference. It is important to make Channel A the direct reference channel, and make Channel B or C the channel to be calibrated (using the current probe).

Calibrating the Power Analyzer

Set up the power analyzer as follows:

1. Switch on the power to the unit and wait for it to show both channels.
2. Press the Channel 1 Select key and use the cursor movement keys to select Channel 1 as Ia.
3. Press the Channel 2 Select key and use the cursor movement keys to select Channel 2 as Ib.
4. Set the SCALE for Ib to the nominal CT ratio (e.g. 100.00, see example 1).
5. Connect the direct current source to current input A (Channel 1) and the current probe leads to current input B (Channel 2).
6. Use a current amplitude near the value to be measured. *Make certain that the current source to the Power Analyzer is less than 20 Amps*.
7. Clamp the current probe over one of the leads of current input A leads
8. If the current source is ON, then the CH1 and CH2 on the power analyzer should be indicating two measurements very close in value.
9. Press the CH1 / CH2 key and the analyzer will mathematically compare Channel 2 to Channel 1, and provide the exact magnitude and phase values to program in to the power analyzer.
10. Press the SHIFT and SCALE keys to view the various scale values. Use the cursor keys to move to Ib and press ENTER.
11. Use the cursor keys again to select the correct digit and numerical scale value for magnitude. When the value is correct – with decimal point – press ENTER.
12. Repeat the procedure in 8 and 9 for phase difference (between A and B).

The probe should now be calibrated to the power analyzer, read current directly and compensate for errors in magnitude and phase shift. Three examples follow.

Calibrated Example 1

PROBE: AEMC Model MN170, Clamp-on Current Probe, 100:1 ratio and maximum input current of 75 Amps

Using a Model 1040C as a current source, a Model 931A to measure current, calibration was performed at 5 Amps. Measurements at other values were as follows:

1040C	CH A	CH B	CH1/CH2	ϕ °
0.1	0.1000	0.1000	1.0004	0.21
1.0	1.0007	1.0014	0.9994	0.18
2.0	2.0003	2.0012	0.9995	0.13
3.0	3.0000	3.0008	0.9997	0.08
4.0	4.0004	4.0010	0.9999	0.04
5.0	5.0019	5.0020	1.0000	0.00

From left to right, the first three rows are in amps. The fourth row is dimensionless (A/A), and the last row is the phase difference in degrees between the two measurement channels (Channel 2 compared to 1).

```
  SCALE FACTOR GAIN & PHASE SELECTIONS
Vab  1.0000    +0.00  Ia →1.0000    +0.00
Vbc  1.0000    +0.00  Ib  100.00    +0.00
Vca  1.0000    +0.00  Ic  1.0000    +0.00
Van  1.0000    +0.00  PT  1.0000    +0.00
Vbn  1.0000    +0.00  CT  1.0000    +0.00
Vcn  1.0000    +0.00  PT/CT   ON    * OFF
Scale Factor * Enable   Disable
```

The screen above shows the nominal CT scale setting prior to actual calibration.

In this example, the Model 931A was connected as in Figure 3 with only the advertised current probe ratio programmed in for the magnitude of Ib. With only one turn for N1, the programmed scale value for Ia (N1) was 1.0000, and the programmed scale value for Ib (N2) was 100.00. Next, the current source is applied and the VOLTS/AMPS key was pressed to observe the Ia and Ib readings stabilize.

```
CH1 Rms     5.0190     2.47
                       Amps
CH2 Rms     4.9871     Amps
CH1=Ia  Wide-Band      28 Oct 1999
CH2=Ib               Thu 14:42:24
```

After this the CH1/CH2 key was pressed to observe the current ratio, for magnitude and phase.

```
CH1/CH2     1.0064      P/U
PHASE         2.47      Deg
CH1=Ia  Wide-Band      28 Oct 1999
CH2=Ib               Thu 14:42:58
```

With a magnitude ratio of 1.0064 and a probe turns ratio of 100, multiply the ratio above by 100 to get 100.64 and enter this value in for Ib magnitude. Do the same for the phase error between Ia and Ib of 2.47 degrees. When complete, current Ib should agree with current Ia at the same current that the ratios were determined. See the screen printout from the Model 931A scale values.

```
  SCALE FACTOR GAIN & PHASE SELECTIONS
Vab  1.0000    +0.00  Ia   1.0000   +0.00
Vbc  1.0000    +0.00  Ib →100.64    +2.47
Vca  1.0000    +0.00  Ic   1.0000   +0.00
Van  1.0000    +0.00  PT   1.0000   +0.00
Vbn  1.0000    +0.00  CT   1.0000   +0.00
Vcn  1.0000    +0.00  PT/CT    ON   * OFF
Scale Factor * Enable   Disable
```

Incidentally, if higher current values need to be calibrated (beyond the range of the Model931A) a coil of wire may be substituted for N1. This method limits the direct current to the Model 931A but increases the apparent current sensed by the probe. This procedure will be explained in the next example

Calibrated Example 2

PROBE: AEMC MD304, Clamp-on current probe, 100:1 ratio and 600 Vrms maximum input voltage

In this second example we want to calibrate the probe at a current of 125 Amps. However, with a current source limit of 7 Amps and maximum measuring limit (with the Model 931A) of 20 Amps, another method is required.

A coil of wire with a known number of turns can replace a high current source for the probe. The Model 931A can be scaled to the desired ratio. In this example we used a 25-turn coil and set Channel 1 (A) to a turns ratio of 25 (for N1) instead of 1. This was done to make both readings agree for better comparison and consistent ratio. The screen below illustrates how the initial scale factors were set to arrive at a calibrated scale. *See test setup with coil of wire in Figure 4.*

```
  SCALE FACTOR GAIN & PHASE SELECTIONS
Vab →1.0000    +0.00  Ia   25.000   +0.00
Vbc  1.0000    +0.00  Ib   100.00   +0.00
Vca  1.0000    +0.00  Ic   1.0000   +0.00
Van  1.0000    +0.00  PT   1.0000   +0.00
Vbn  1.0000    +0.00  CT   1.0000   +0.00
Vcn  1.0000    +0.00  PT/CT    ON   * OFF
Scale Factor * Enable   Disable
```

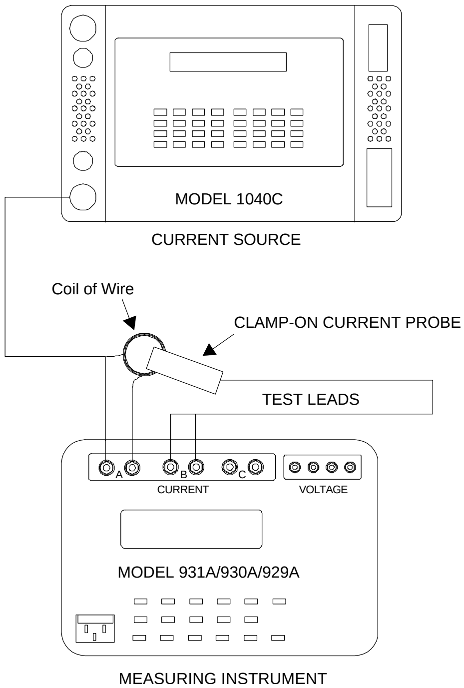


Figure 4

With these initial scale factors installed, we adjusted the current to 5 Amps and read the two currents as follows:

```
CH1 Rms      125.47     -0.01
                         Amps
CH2 Rms      125.28      Amps
CH1=Ia  Wide-Band      28 Oct 1999
CH2=Ib                Thu 15:11:01
```

Next, we press the CH1/CH2 key to get the current magnitude and phase ratios.

```
CH1/CH2      1.0015      P/U
PHASE        -0.01       Deg
CH1=Ia  Wide-Band      28 Oct 1999
CH2=Ib                Thu 15:12:50
```

With these two ratios we can install these calibration scale factors and make some measurements.

```
  SCALE FACTOR GAIN & PHASE SELECTIONS
Vab →1.0000    +0.00  Ia   25.000    +0.00
Vbc  1.0000    +0.00  Ib   100.15    -0.01
Vca  1.0000    +0.00  Ic   1.0000    +0.00
Van  1.0000    +0.00  PT   1.0000    +0.00
Vbn  1.0000    +0.00  CT   1.0000    +0.00
Vcn  1.0000    +0.00  PT/CT    ON    * OFF
Scale Factor  * Enable    Disable
```

For negative, phase-angle, scale factors it is necessary to move the cursor to one digit to the left of the most-significant digit to get the negative sign.

After installing the above probe scaling we made some measurements at simulated currents, shown below.

1040C	CH1	CH2	CH1/CH2	ϕ°
1.0	25.076	24.407	1.0277	0.83
2.0	50.260	49.583	1.0091	0.17
3.0	75.329	74.628	1.0089	0.17
4.0	100.35	99.985	1.0037	0.06
5.0	125.42	125.40	1.0001	-0.01
6.0	150.55	150.95	0.9973	-0.06

From left to right, the first three rows are in amps. The fourth row is dimensionless (A/A), and the last row is the phase difference in degrees between the two measurement channels (Channel 2 compared to 1).

Calibrated Example 3

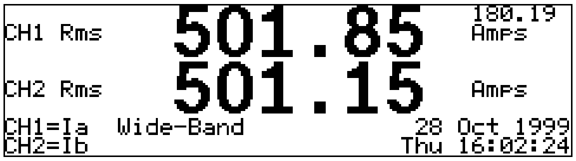
PROBE: AEMC SD601A Clamp-on current probe, 1000:1 ratio and 1000 Amps maximum input

In example 3 we want to calibrate the probe at a current of 500 Amps. However, with a current source limit of 7 Amps and maximum measuring limit (with the Model 931A) of 20 Amps, we will use the same method as in example 2 but with a larger coil.

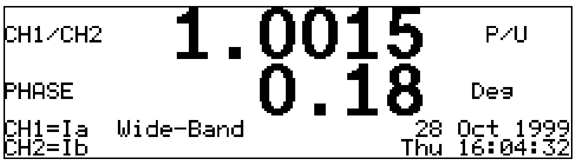
A coil of wire with a known number of turns can replace a high current source for the probe. The Model 931A can be scaled to the desired ratio. In this example we used a 100-turn coil and set Channel 1 (A) to a turns ratio of 100 (for N1) instead of 1. This was done to make both readings agree for better comparison and consistent ratio. The screen below illustrates how the initial scale factors were set to arrive at a calibrated scale.

```
  SCALE FACTOR GAIN & PHASE SELECTIONS
Vab  1.0000    +0.00  Ia   100.00    +0.00
Vbc  1.0000    +0.00  Ib   1000.0 →  +0.00
Vca  1.0000    +0.00  Ic   1.0000    +0.00
Van  1.0000    +0.00  PT   1.0000    +0.00
Vbn  1.0000    +0.00  CT   1.0000    +0.00
Vcn  1.0000    +0.00  PT/CT    ON    * OFF
Scale Factor  * Enable    Disable
```

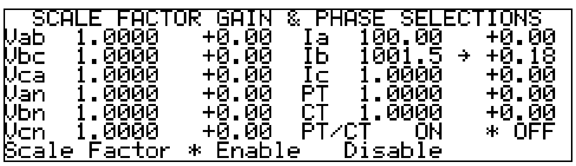
With these initial scale factors installed, we adjusted the current to 5 Amps and read the two currents as follows:



Next, we press the CH1/CH2 key to get the current magnitude and phase ratios.



With these two ratios we can install these calibration scale factors and make some measurements.



For negative, phase-angle, scale factors it is necessary to move the cursor to one digit to the left of the most-significant digit to get the negative sign.

After installing the above probe scaling we made some measurements at simulated currents, shown below.

From left to right, the first three rows are in amps. The fourth row is dimensionless (A/A), and the last row is the phase difference in degrees between the two measurement channels (Channel 2 compared to 1).

1040C	CH1	CH2	CH1/CH2	$\phi°$
5.0	501.98	502.00	1.0000	0.00
4.0	401.87	401.89	1.0000	0.02
3.0	301.28	301.13	1.0005	0.03
2.0	200.50	200.80	0.9985	0.06
1.0	100.31	100.58	0.9973	0.10

Summary

Using a current probe and any of the Arbiter power analyzers (Model 931A / 930A / 929A) it is possible to make very accurate measurements outside the range of the instrument. Secondly, it is possible to account for the magnitude and phase angle inaccuracies due to using a current probe. By doing this, the above measurements can be very accurate.

Other devices can also be used to increase the range of the Arbiter Power DSA series of analyzers. One of these is the 400-Amp precision CT described below.

Accessories

400 Amp Direct Input Adapter

Arbiter also produces a 400-Amp, 20:1 precision CT. This is a direct input CT adapter, with 0.1% accuracy over the full range. It attaches to the power analyzer current input terminals with lugs. Order part number 09311A.